# Air Force Research Laboratory


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## Solar Input for Ionospheric/Thermospheric modeling

CCMC
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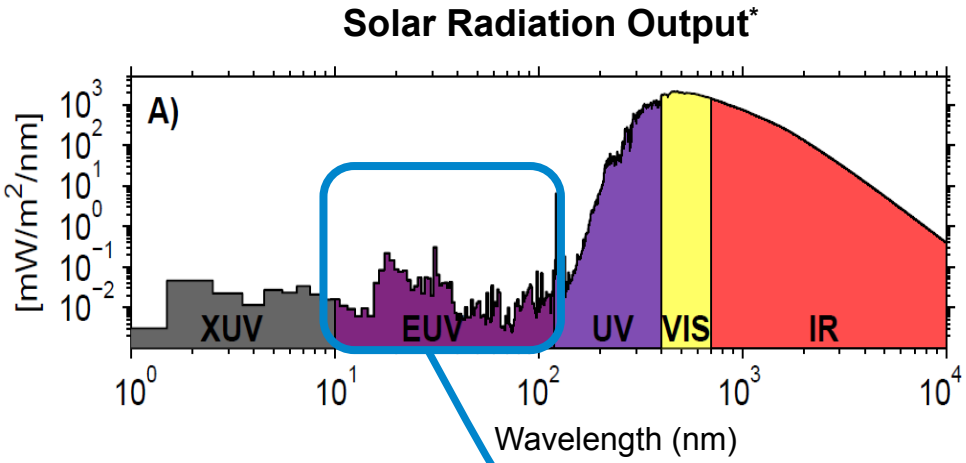
AFRL

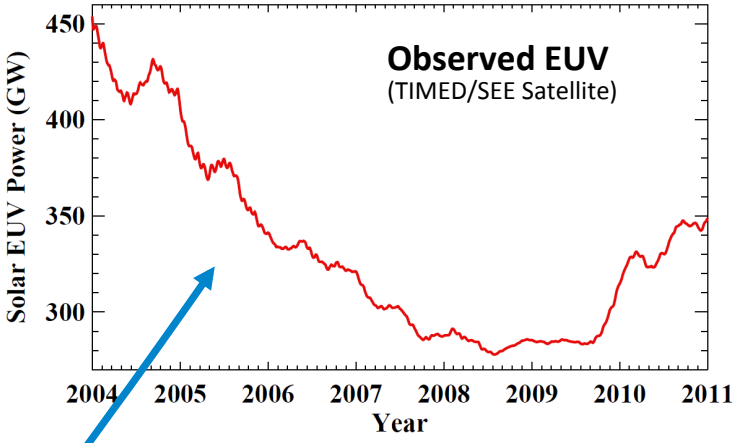
# Introduction:
## solar indices



- Solar extreme ultraviolet (EUV) radiation is absorbed in the Earth's upper atmosphere and drives ionization & heating




EUV Band (15 to 105 nm)




Thermospheric and Ionospheric models need an estimation of EUV…

…however, EUV is not observable from ground.

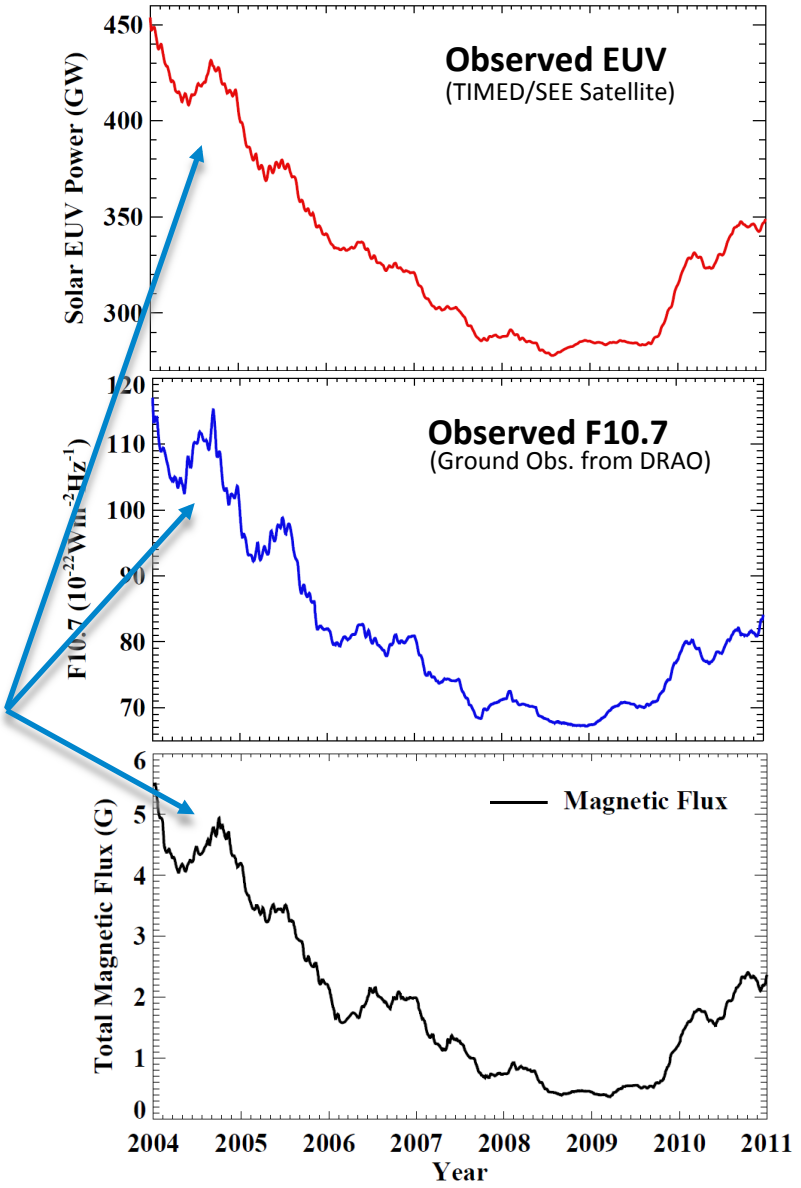
*Figure from: Ermolli et al. 2013, Atmos. Chem. Phys., 13, 3945

TIMED/SEE – NASA Satellite (2002 to present)

# Introduction:
## solar indices



- Solar extreme ultraviolet (EUV) radiation is absorbed in the Earth's upper atmosphere and drives ionization & heating
- Several solar indices have been used as proxies for EUV for periods without satellite measurements, e.g., the solar radio flux at 10.7 cm ($F_{10.7}$, referred to as "F10.7")
- The F10.7 data is extremely well calibrated and reliable; daily observations since 1947
- The EUV & F10.7 time series agree well since both signals are modulated from additional heating provided from solar magnetic fields



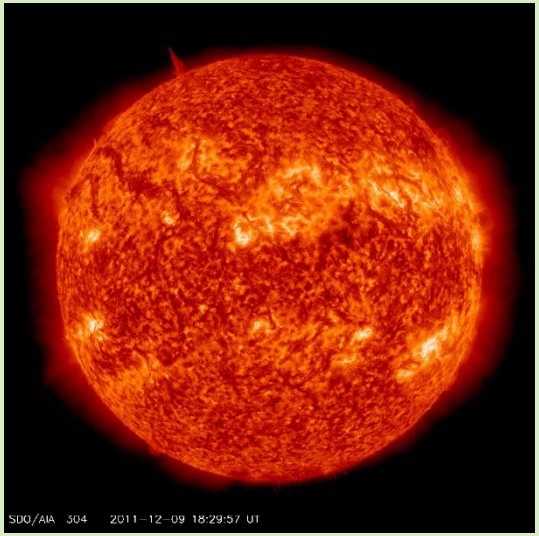

DRAO – Dominion Radio Astrophysical, Canada
TIMED/SEE – NASA Satellite (2002 to present)

# Introduction:
## F10.7, EUV, and solar magnetic fields

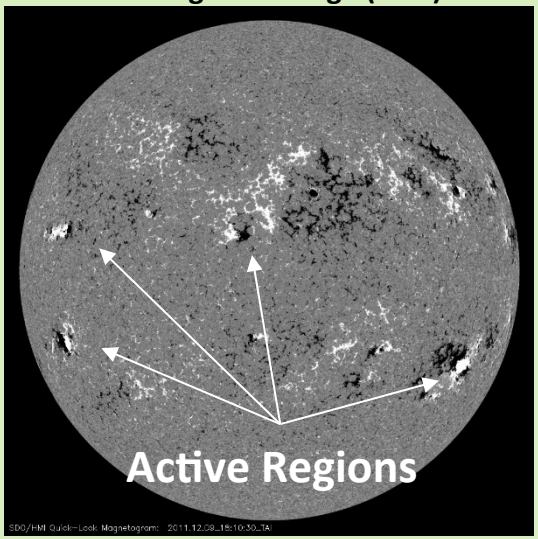


EUV, Magnetic, and 10.7 cm Full-Disk Images of the Sun

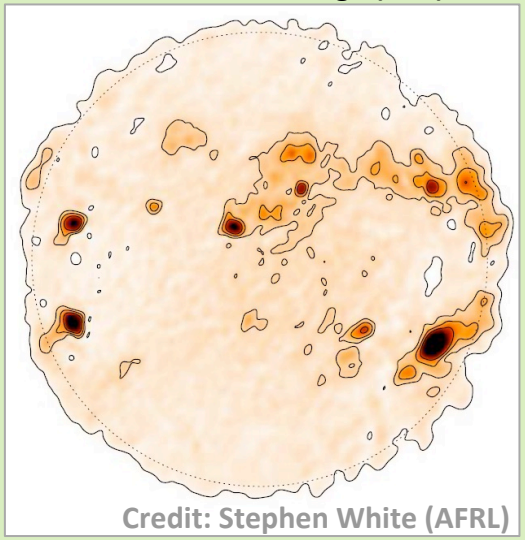
**Solar EUV Image (SDO)**




**Solar Magnetic Image (SDO)**




**Solar 10.7 cm Image (VLA)**



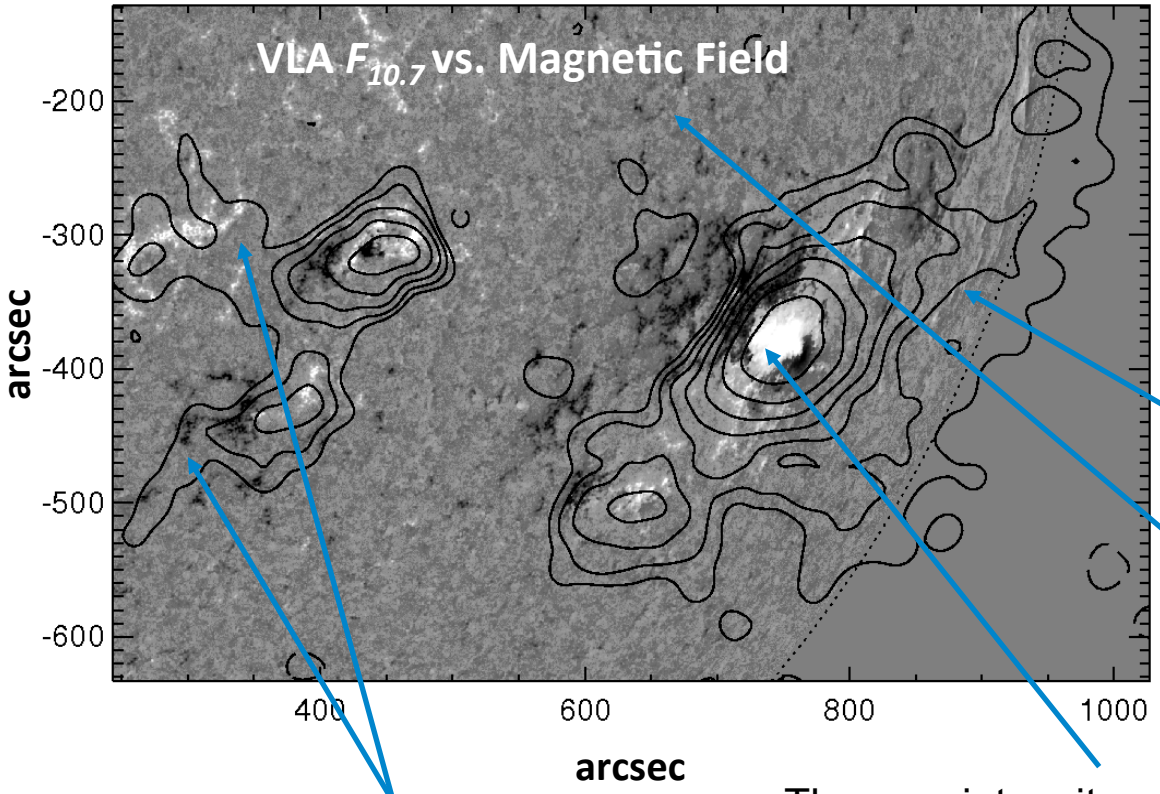

- EUV & radio 10.7 cm signal sources align with magnetic active regions
- Integrated comparison first done by *Parker et al. 1998, Solar Physics, 177, 229*
  - for ADAPT development, full-disk indices provide feedback/validation

SIFT = Solar Indices Forecasting Tool
SDO = NASA's Solar Dynamics Observatory spacecraft
VLA = Very Large Array; Socorro, NM

# Introduction:
## *solar* $F_{10.7}$ & magnetic field



*VLA observation at 2.8 GHz (i.e., 10.7 cm); courtesy of Stephen White (AFRL).*




*Very Large Array (VLA); Socorro, NM.*

Contours illustrate radio flux intensity at 10.7 cm

Background image is a magnetogram from SDO/HMI

Weak magnetic fields also associated with radio signal

The max intensity contour clearly peaks with strong magnetic field

**For more discussion on $F_{10.7}$ sources, see:**
***Schonfeld et al. 2015, ApJ, 88, 29***

# *SIFT* $F_{10.7}$ & *VUV* Empirical Models



The SIFT* F10.7 & VUV empirical models, based on Henney et al. 2012 & Henney et al. 2015, use the near-side magnetic field estimates from future ADAPT maps:

$$F_{model} = m_0 + m_1 S_w + m_2 S_s$$

where

$$S_w = 1/\sum \omega_\theta \sum 25G < |B_r| < 150G \, |B_r| \, \omega_\theta$$

**Weak Field Sum**

and

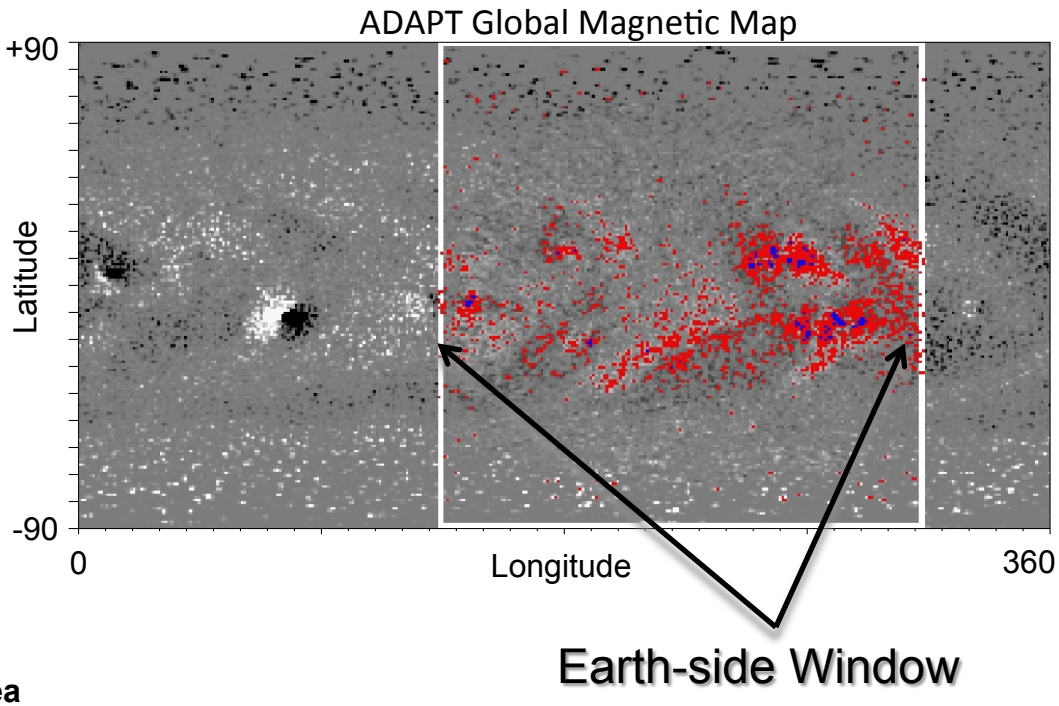
$$S_s = 1/\sum \omega_\theta \sum 150G \leq |B_r| \, \omega_\theta$$

**Strong Field Sum**

**Total Window Area**

**Unsigned Radial Magnetic Field**

**Area**




**For more on the $F_{10.7}$ & VUV modeling, see:**
***Henney et al. 2015, Space Weather, 13***

* SIFT – *Solar Indices Forecasting Tool*

# Modeling XUV, EUV, & FUV



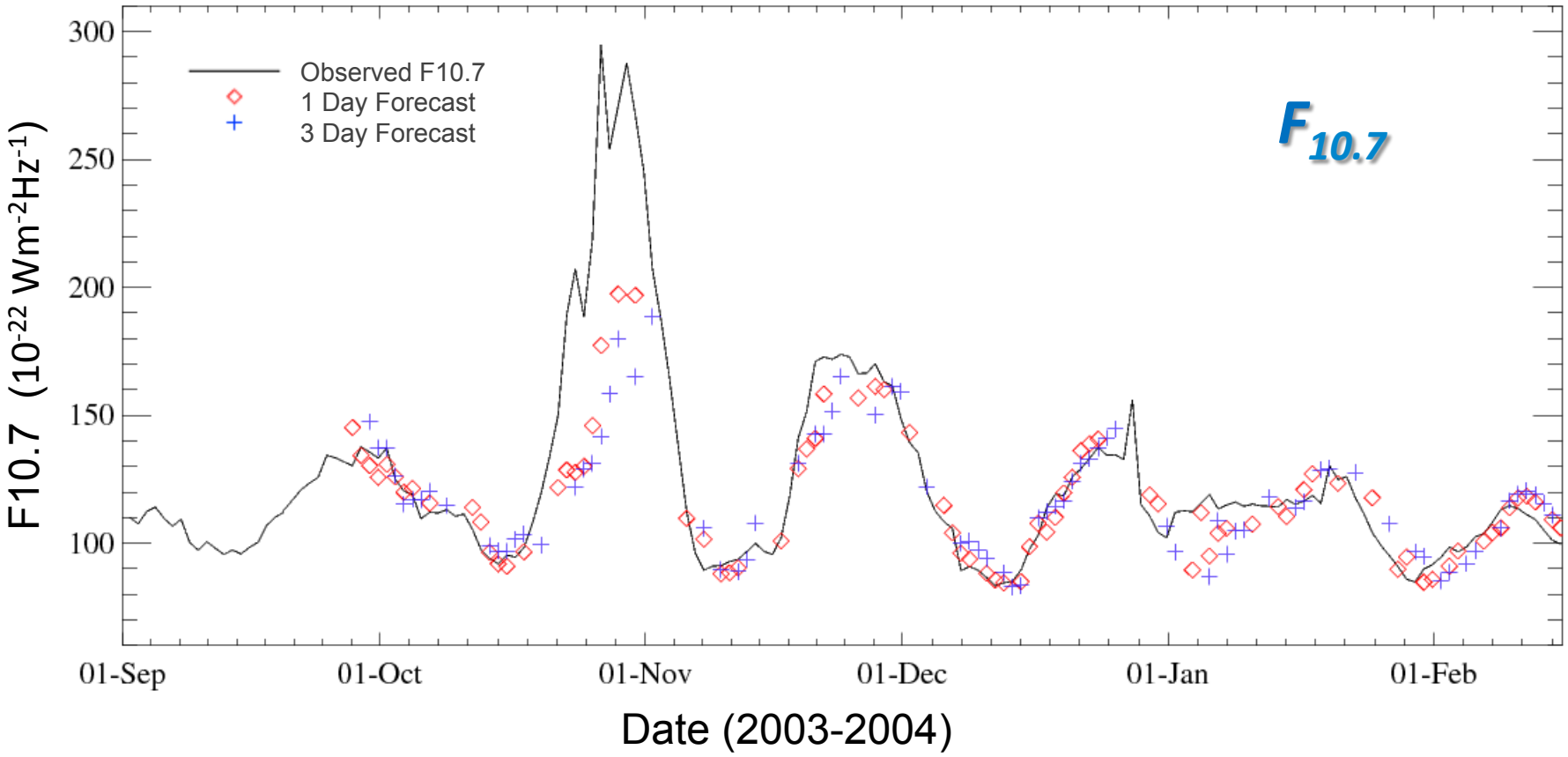
Thermospheric models typically divide the VUV spectral regions of interest into 37 bands within the **XUV/ EUV/FUV** intervals, where XUV is 0.1-10 nm, EUV is 10-121 nm, and FUV is 121-200 nm [Solomon and Qian, 2005]:

| # | Wavelength | # | Wavelength | # | Wavelength | # | Wavelength |
|---|---|---|---|---|---|---|---|
| 1 | 0.1-0.4nm | 11 | 54.0-65.0nm | 21 | 98.7-102.7nm | 31 | 140.0-145.0nm |
| 2 | 0.4-0.8nm | 12 | 65.0-79.8nm (low) | 22 | 102.7-105.0nm | 32 | 145.0-150.0nm |
| 3 | 0.8-1.8nm | 13 | 65.0-79.8nm (high) | 23 | 105.0-110.0nm | 33 | 150.0-155.0nm |
| 4 | 1.8-3.2nm | 14 | 79.8-91.3nm (low) | 24 | 110.0-115.0nm | 34 | 155.0-160.0nm |
| 5 | 3.2-7.0nm | 15 | 79.8-91.3nm (mid) | 25 | 115.0-120.0nm | 35 | 160.0-165.0nm |
| 6 | 7.0-15.5nm | 16 | 79.8-91.3nm (high) | 26 | 121.6nm Lyman-α | 36 | 165.0-170.0nm |
| 7 | 15.5-22.4nm | 17 | 91.3-97.5nm (low) | 27 | 120.0-125.0nm | 37 | 170.0-175.0nm |
| 8 | 22.4-29.0nm | 18 | 91.3-97.5nm (mid) | 28 | 125.0-130.0nm | | |
| 9 | 29.0-32.0nm | 19 | 91.3-97.5nm (high) | 29 | 130.0-135.0nm | | |
| 10 | 32.0-54.0nm | 20 | 97.5-98.7nm | 30 | 135.0-140.0nm | | |

- For this study, we used solar irradiances measured by the Solar EUV Experiment (SEE) on NASA's TIMED mission [Woods et al. 2002], which has been operating since early 2002.

# ADAPT/SIFT Forecasting: F10.7

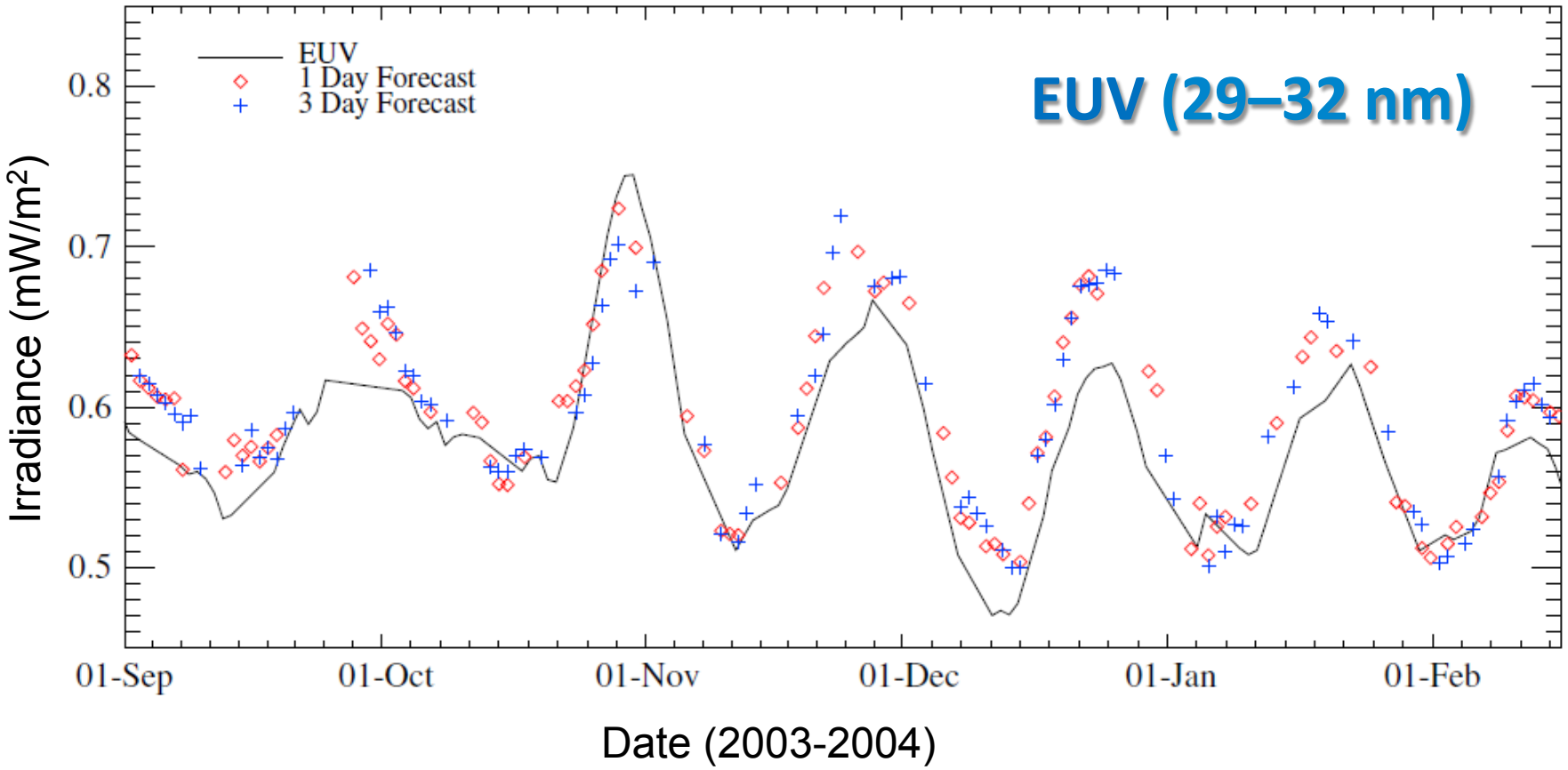





- Observed solar radio flux at 10.7 cm from DRAO, Canada

# ADAPT/SIFT Forecasting: EUV



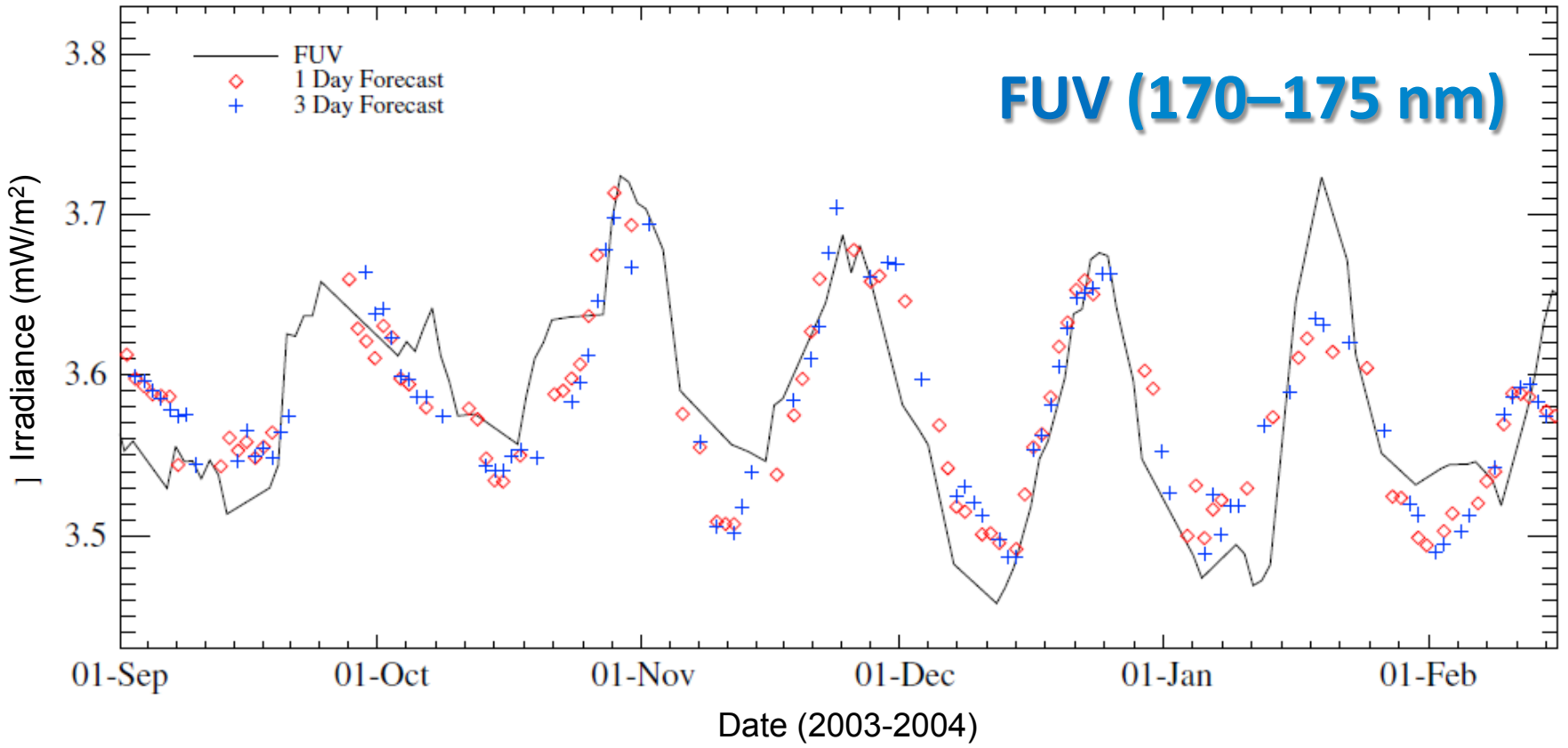



*Henney et al. 2015, Space Weather, 13, 141-153*

- Observed solar irradiance measured by the Solar EUV Experiment (SEE) on NASA's TIMED mission [Woods et al. 2002]

# ADAPT/SIFT Forecasting: FUV



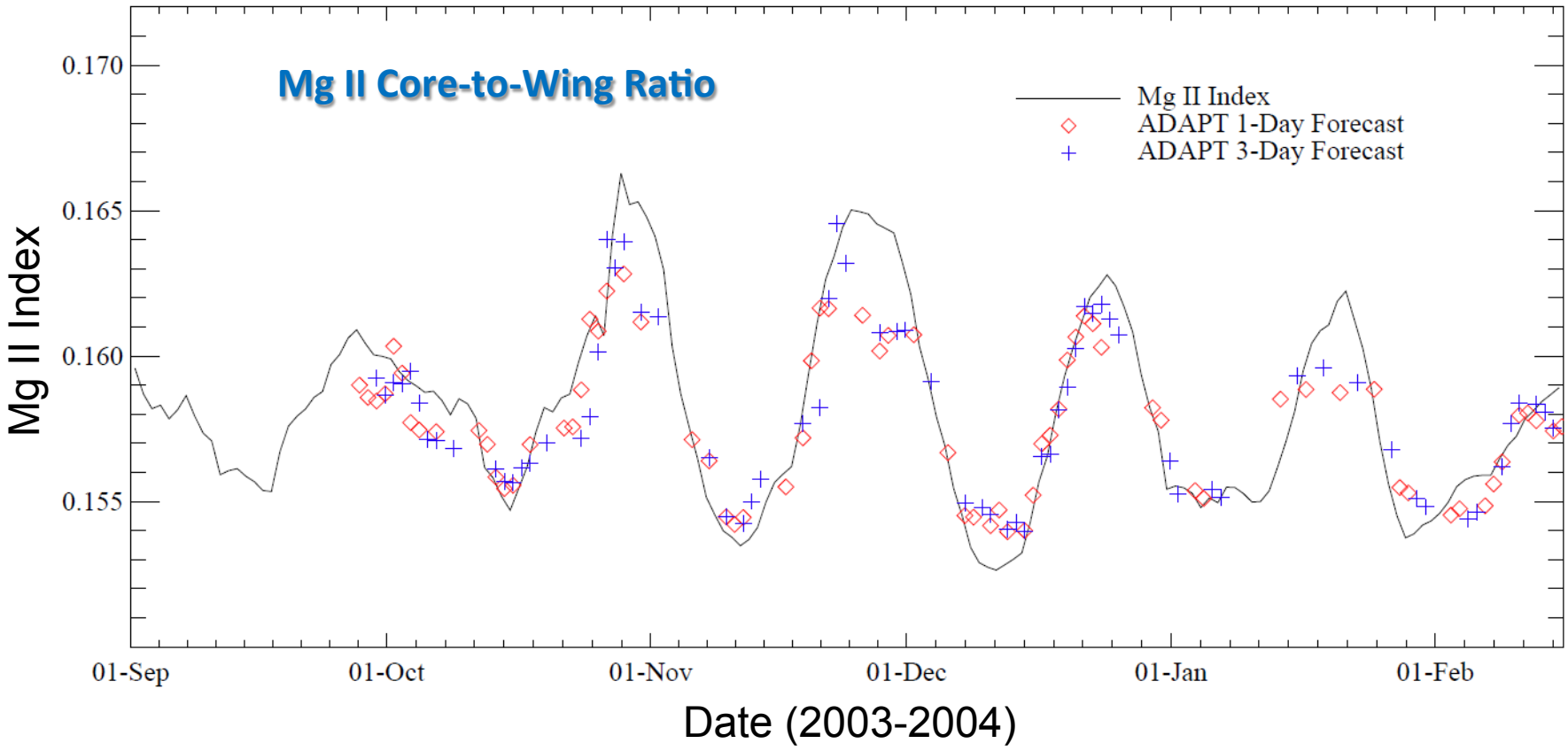



*Henney et al. 2015, Space Weather, 13, 141-153*

- Observed solar irradiance measured by the Solar EUV Experiment (SEE) on NASA's TIMED mission [Woods et al. 2002]

# ADAPT/SIFT Forecasting: Mg II Index






- Mg II Index from GOME/SCIAMACHY (via Mark Weber; Composite V5)

# Summary:
## ADAPT/SIFT predictions online



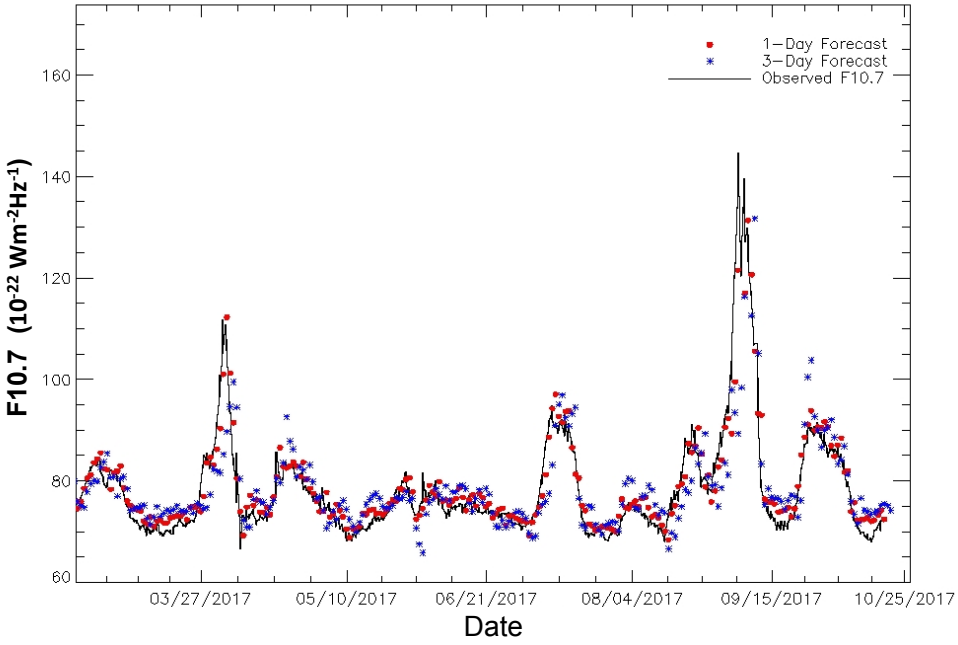
**ADAPT Maps and SIFT Forecasts are now online:**

- ADAPT runs 24/7 in a prototype mode at the National Solar Observatory (NSO) generating global maps every 2 hours
- SIFT utilizes the ADAPT maps in near real-time, providing 1, 3, and 7 day advance forecast values of F10.7, SSN, & Mg II core-to-wing

**SIFT F10.7 Forecast File**

```
: Product : adapt_f107_forecast.txt
: Created : 2014 10 24 2147 UT
: Date : 2014 10 24
: DOY : 297
: Model: ADAPT-F10.7
: Version :  5.0212
: POC : CJ Henney (USAF/AFRL)
: POC Email : adapt@noao.edu
: Data Input : GONG
: Resolution [deg / pixel] : 1.00
: Fit-function : m0 + m1*M_P + m2*M_A
: Forecast :  0,     1,     3,     7
: m0 :    66.08,  65.00,  64.00,  63.00
: m1 :     8.51,   8.00,   9.00,  10.00
: m2 :    16.56,  17.00,  18.00,  19.00
: M_P (plage mag-field) Lower Limit [G] :  25.0
: M_A (active region mag-field) Lower Limit [G] : 150.0
: Missing Value :  -1.0
: Record Count : 12
#
#| Table Notes
#
#   JD - Julian Date
#    M - Missing = 0 - forecast available
#              = 1 - forecast missing or pending
#    Q - Quality = 0 - input data nominal
#              = 1 - entry with >2 days w/o model input data
#    H - Helioseismic data within forecast window:
#              = 0-none, 1-farside, 2-nearside, 3-both farside & nearside
#   UT - forecast time, Coordinated Universal Time, HHMM format
#   LastMag - fractional days since last mag data assimilation
#   NearF10 - fractional days since last F10 obs differenced w/ 0d value
#   Diff - obs_model offset = (F10.7 obs value) - (0-day model prediction)
#   F10.7 Forecast - 0day, 1day, 3day, 7day model estimates plus diff offset
#
#| Observed F10 Data Source
#
#   http://www.swpc.noaa.gov/ftpdir/lists/radio/7day_rad.txt
#
#| ADAPT - F10.7 Forecast [s.f.u. @ earth distance]
#
#      JD        M  Q  H   UT    LastMag  NearF10  Diff     0d      1d      3d      7d
#-------------------------------------------------------------------------------------
  2456954.5000  0  0  0  0000    0.087    0.042    33.0   202.0   207.2   212.4   144.0
  2456954.5833  0  0  0  0200    0.011    0.125    33.0   204.9   209.9   214.8   144.7
  2456954.6667  0  0  0  0400    0.004    0.208    33.0   204.2   209.1   213.9   143.9
  2456954.7500  0  0  0  0600    0.087    0.292    33.0   203.1   208.5   212.5   143.0
  2456954.8333  0  0  0  0800    0.171   -0.375    52.9   222.0   227.8   231.0   162.3
  2456954.9167  0  0  0  1000    0.254   -0.292    52.9   221.0   227.4   230.5   161.7
  2456955.0000  0  0  0  1200    0.338   -0.208    52.9   220.1   227.1   230.0   161.4
  2456955.0833  0  0  0  1400    0.421   -0.125    52.9   219.3   226.7   229.4   161.3
  2456955.1667  0  0  0  1600    0.504   -0.042    52.9   217.7   226.5   228.6   160.9
  2456955.2500  0  0  0  1800    0.587    0.042    52.9   215.7   226.3   228.0   160.8
  2456955.3333  1  1  0  2000   -1.000   -1.000    -1.0    -1.0    -1.0    -1.0    -1.0
  2456955.4167  1  1  0  2200   -1.000   -1.000    -1.0    -1.0    -1.0    -1.0    -1.0
```

**Real-time F10.7 Comparison**



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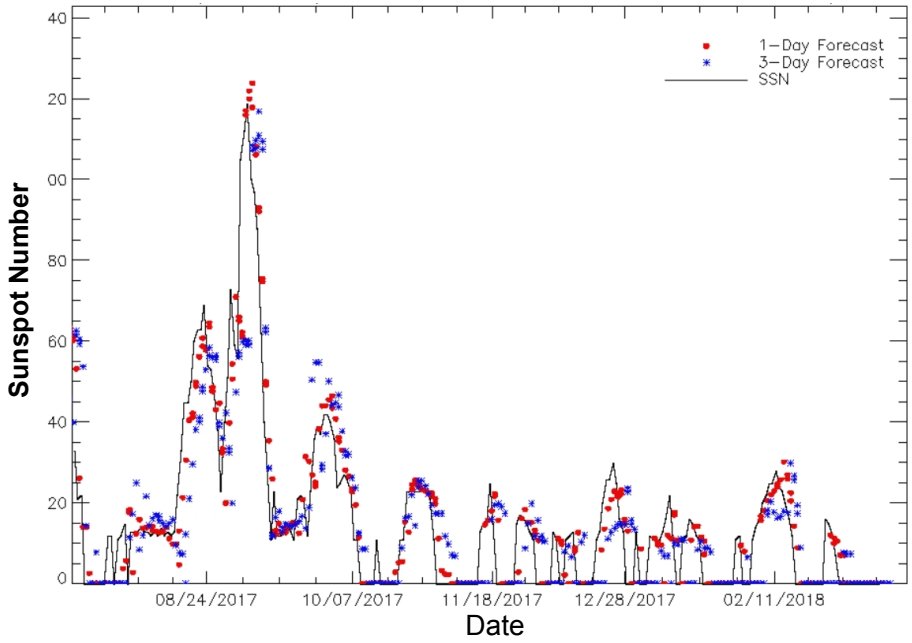
**SIFT SSN Forecast File**

```
: Product : adapt_ssn_forecast.txt
: Created : 2018 03 14 2222 UT
: Date : 2018 03 14
: DOY :  73
: Model: ADAPT/SIFT-SSN
: SIFT Version :  1.05
: ADAPT Version : 0.7.09
: POC : Carl Henney (USAF/AFRL)
: POC Email:adapt@nso.edu
: Data Input : GONG (NSO/NISP)
: Resolution [deg / pixel] :  1.00
: Fit-function : m0 + m1*M_P + m2*M_A
: M_P (plage mag-field) Lower Limit [G] :  20.0
: M_A (active region mag-field) Lower Limit [G] : 150.0
: Record Count : 15
#
#| Table Notes
#
#   JD - Julian Date
#    M - Missing = 0 - forecast available
#              = 1 - forecast missing or pending
#    Q - Quality = 0 - Good: input data nominal
#              = 1 - Poor: large diff, pending, or >2 days w/o data
#              = 2 - TEST: model pipeline testing - non-forecast data
#    H - Helioseismic data within forecast window:
#              = 0-none, 1-farside, 2-nearside, 3-both far & near
#   UT - forecast time, Coordinated Universal Time, HHMM format
#   LastMag - fractional days since last mag data assimilation
#   LastObs - fractional days since last Index obs differenced w/ 0d value
#   Diff - obs_model offset = (Index obs value) - (0-day model prediction)
#   Index Forecast - 0day, 1day, 3day, 7day model estimates plus diff offset
#
#| Observed Index Data Source
#
#   WDC-SILSO, Royal Observatory of Belgium, Brussels:
#   http://www.sidc.be/silso/DATA/SN_d_tot_V2.0.txt
#
#| ADAPT/SIFT - SSN Forecast
#
#      JD        M  Q  H   UT    LastMag  LastObs  Diff    0d     1d     3d     7d
#-------------------------------------------------------------------------------
  2458191.2500  0  1  0  1800     0.025    0.250   -3.3    0.0    0.0    0.0    0.0
  2458191.3333  0  1  0  2000     0.108    0.333   -3.1    0.0    0.0    0.0    0.0
  2458191.4167  0  1  0  2200     0.192    0.417   -3.1    0.0    0.0    0.0    0.0
  2458191.5000  0  1  0  0000     0.275    0.500   -3.1    0.0    0.0    0.0    0.0
  2458191.5833  0  1  0  0200     0.358    0.583   -3.0    0.0    0.0    0.0    0.0
  2458191.6667  1  1  0  0400    -1.000   -1.000   -1.0    0.0    0.0    0.0    0.0
  2458191.7500  1  1  0  0600    -1.000   -1.000   -1.0    0.0    0.0    0.0    0.0
  2458191.8333  1  1  0  0800    -1.000   -1.000   -1.0    0.0    0.0    0.0    0.0
  2458191.9167  1  1  0  1000    -1.000   -1.000   -1.0    0.0    0.0    0.0    0.0
  2458192.0000  1  1  0  1200    -1.000   -1.000   -1.0    0.0    0.0    0.0    0.0
  2458192.0833  1  1  0  1400    -1.000   -1.000   -1.0    0.0    0.0    0.0    0.0
  2458192.1667  1  1  0  1600    -1.000   -1.000   -1.0    0.0    0.0    0.0    0.0
  2458192.2500  0  1  0  1800     0.025    0.250   -3.1    0.0    0.0    0.0    0.0
  2458192.3333  0  1  0  2000     0.046    0.333   -3.2    0.0    0.0    0.0    0.0
  2458192.4167  1  1  0  2200    -1.000   -1.000   -1.0    0.0    0.0    0.0    0.0
```

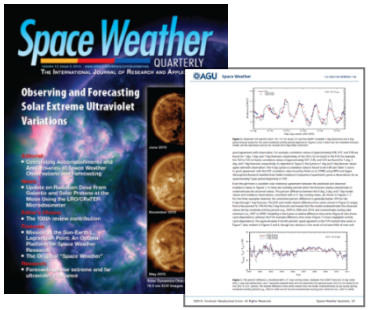
**Real-time SSN Comparison**



# Links & References

- Near real-time ADAPT maps at: ftp://gong2.nso.edu/adapt/maps
- And, $F_{10.7}$ , Mg II, and SSN forecasts at: ftp://gong2.nso.edu/adapt/sift

- Related References:




**Forecasting Solar Extreme and Far Ultraviolet Irradiance**

*Henney, Hock, Schooley, Toussaint, White, Arge 2015,*
***Space Weather, 13, 141-153***
*&* ***Space Weather Quarterly, 12, 19-31***

**Data Assimilation in the ADAPT Photospheric Flux Transport Model**

*Hickmann, Godinez, Henney, Arge 2015,*
***Solar Physics, 209, 1105-1118***

Acknowledgements

ADAPT is supported by the AFRL, AFOSR, and NASA, and this work utilizes data produced collaboratively between AFRL/ADAPT and NSO/NISP.